TTL Cirrus: Using ATTREX to improve climate prediction

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“We are climate modelers and we are here to help”

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Outline

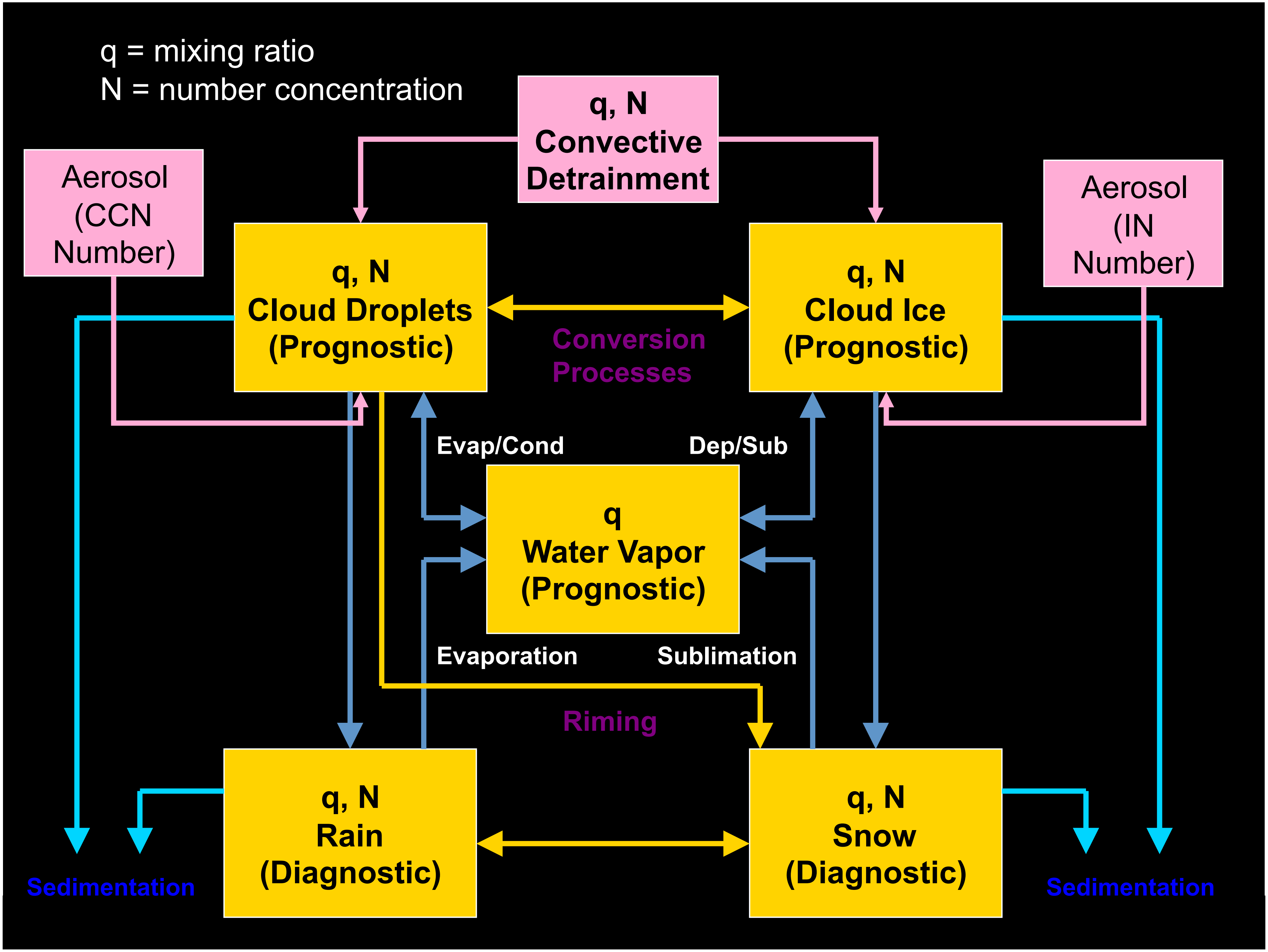
- Focus on Global Models:
  - CAM/WACCM
  - CAM/CARMA
- Other TTL modeling approaches:
  - Mesoscale models (similar to GCM schemes, can use same techniques, codes as GCMs)
  - Trajectory models (Pfister, Jensen)

CAM5 Overview

- Double-moment stratiform cloud microphysics
- Aerosol effects on stratiform droplet & crystal number
- Ice Nucleation and Ice Supersaturation
- Modal Aerosol Model (Liu et al 2010 in prep)
- Bretherton and Park (2009) moist turbulence scheme
- Park and Bretherton (2009) shallow cumulus scheme
- Cloud fraction consistent with PDF of total water
- RRTMG radiation package
- Advanced optics for cloud and aerosol particles
- GCM or specified dynamics ('nudged')

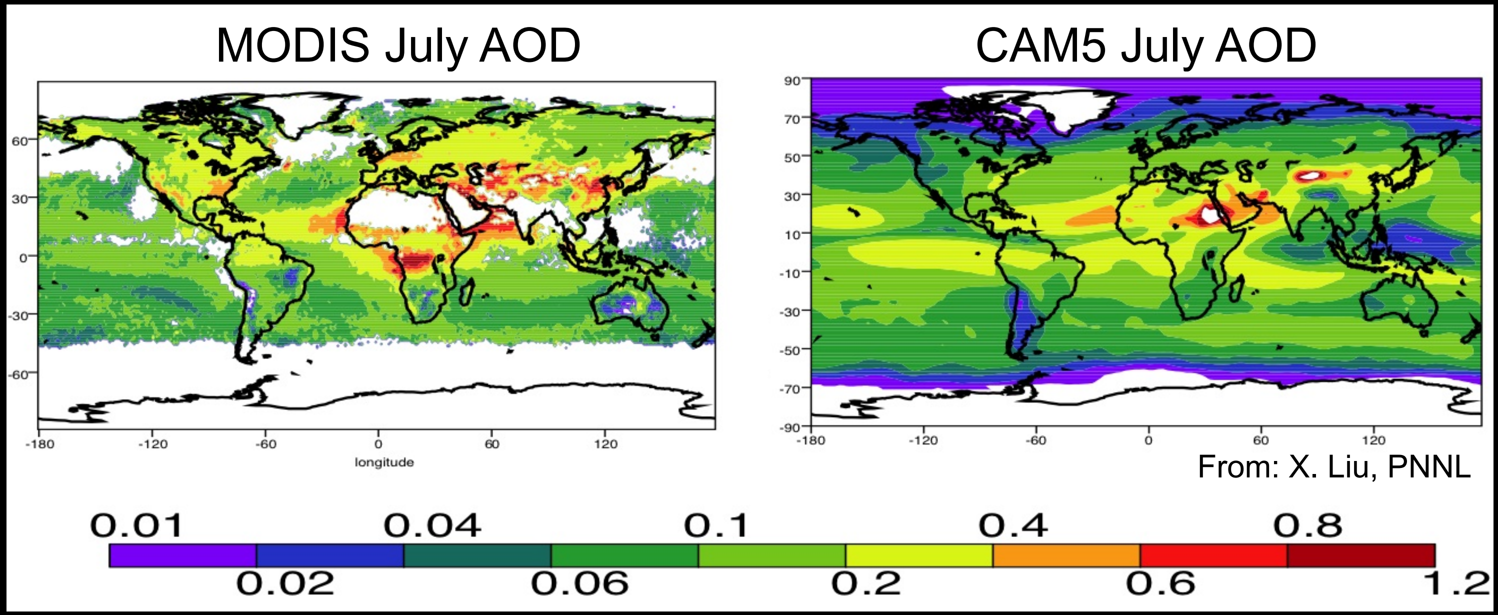
CAM5 (MG) Microphysics

- Two-moment
  - Predicts water/ice mixing ratio & number concentrations
  - Gamma functions, simplified (m=0) for ice
  - 2-moment treatment extends to diagnostic precipitation
- Bergeron processes determine Liquid/ice fraction
  - Vapor deposition, Heterogeneous freezing
  - Ice super-saturation allowed
- Droplet nucleation
  - Abdul-Razzak & Ghan 2000 modified to work at all levels
- Ice Nucleation on aerosols
  - Ice assumed to be spherical for radiation
- Consistent treatment of sub-grid cloud water
  - for all relevant microphysics processes
- Snow treated in radiation code
- Consistent treatment of size distribution in Radiation
  - Shape parameters describe look up table for cloud drops

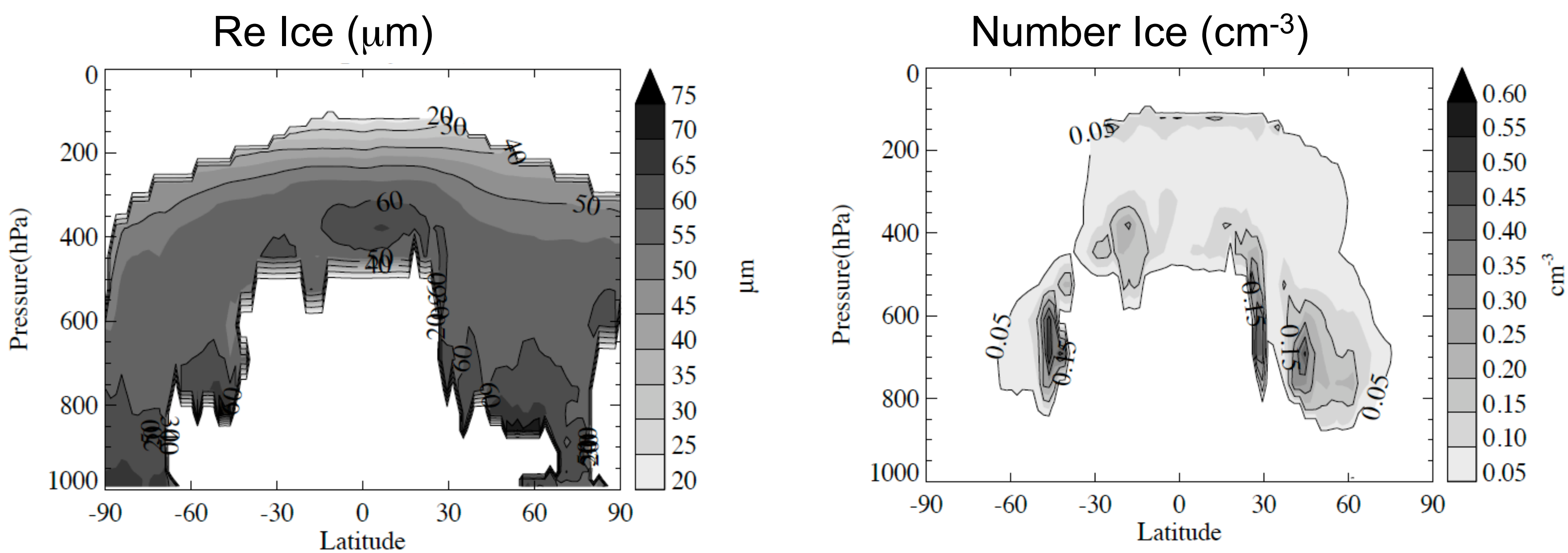

q = mixing ratio
N = number concentration
q, N
Convective
Detrainment
Aerosol
(CCN
Number)
Aerosol
(IN
Number)
q, N
Cloud Droplets
(Prognostic)
q, N
Cloud Ice
(Prognostic)
Conversion
Processes
Evap/Cond
Dep/Sub
q
Water Vapor
(Prognostic)
Evaporation
Sublimation
Riming
q, N
Rain
(Diagnostic)
q, N
Snow
(Diagnostic)
Sedimentation
Sedimentation

CAM5 Aerosols

- Modal Aerosol Model (Liu, Ghan et al)
  - Internal Mixtures, 2 moment (lognormal size dist)
  - 3 modes: Aiken, Accumulation, Coarse
  - Dust, Sea Salt, Black Carbon, Organic Carbon

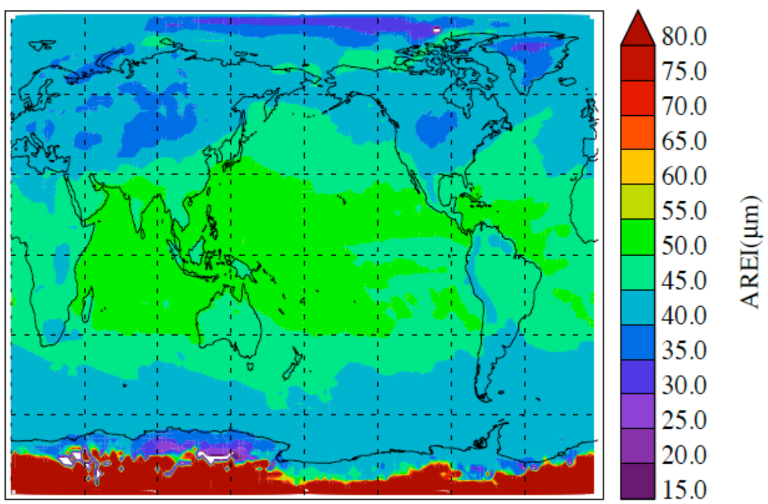


CAM5: Ice Crystal Size & Number

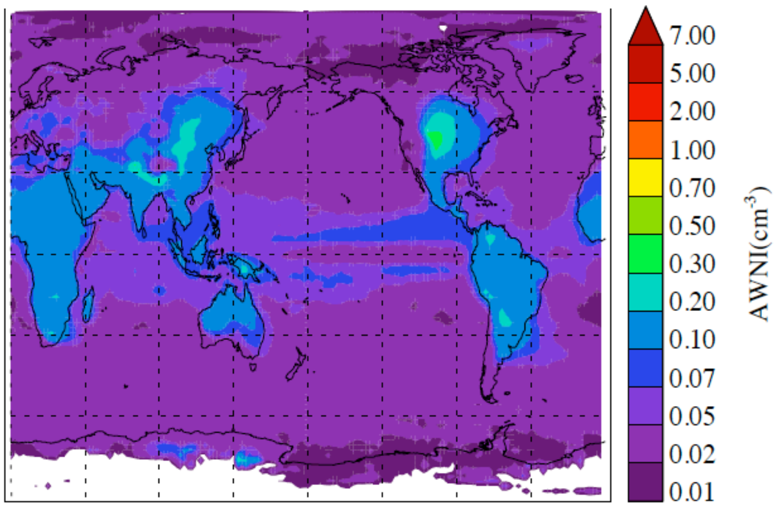


CAM5: Ice size (232hPa)

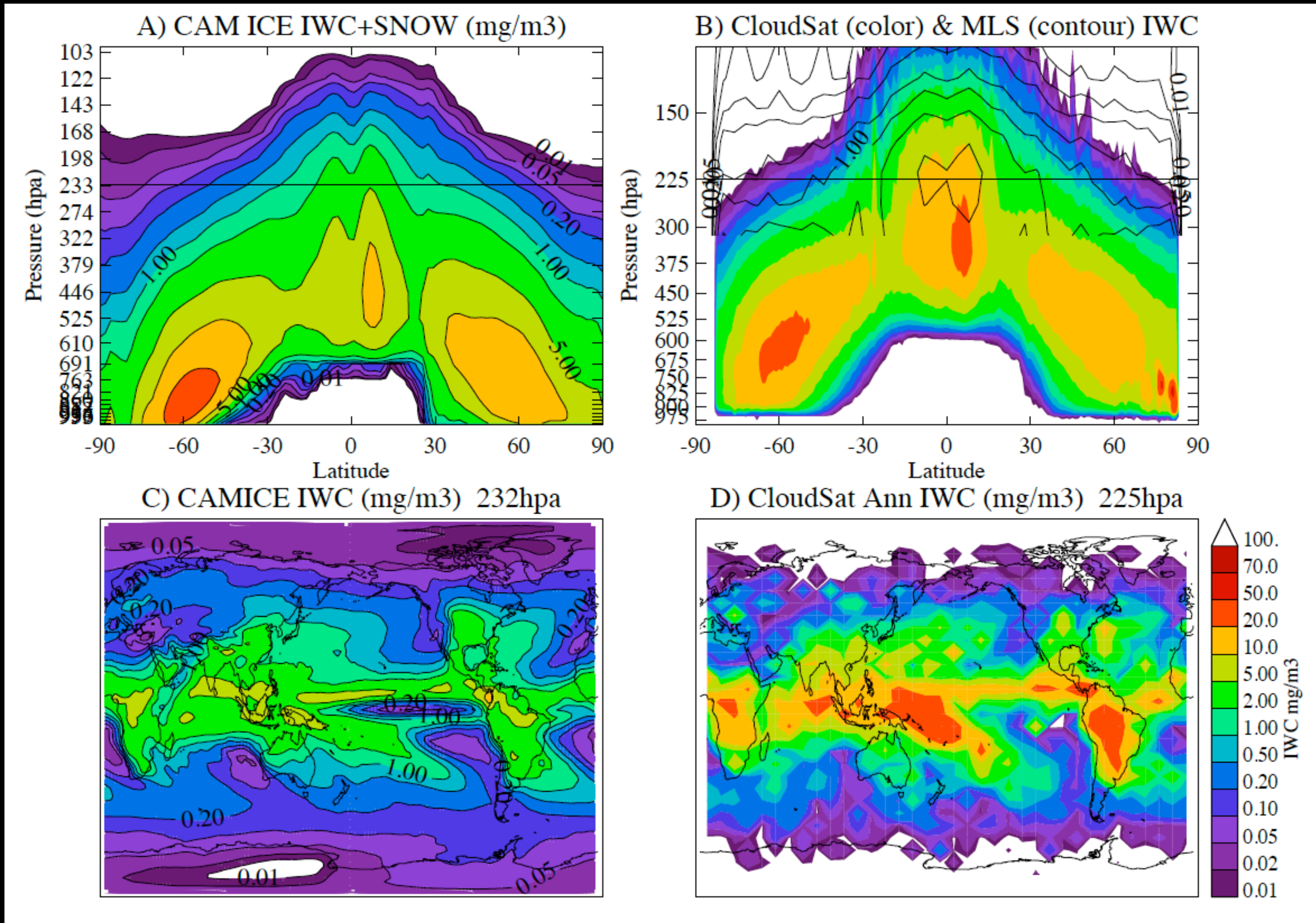
232 hPa Re Ice (μm)



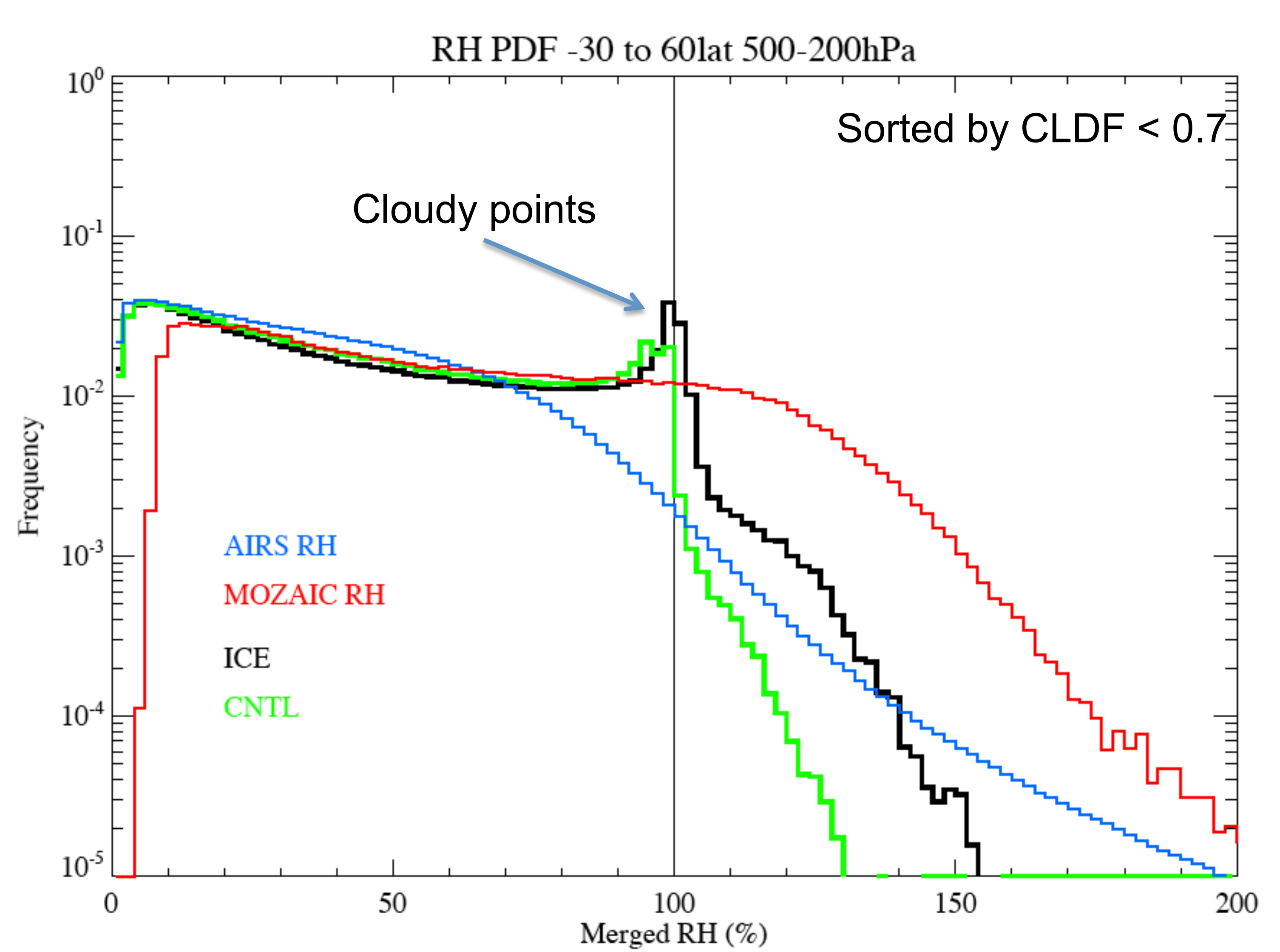
232 hPa Number Ice (cm^{-3})



CAM5 Ice Mass v. CloudSat

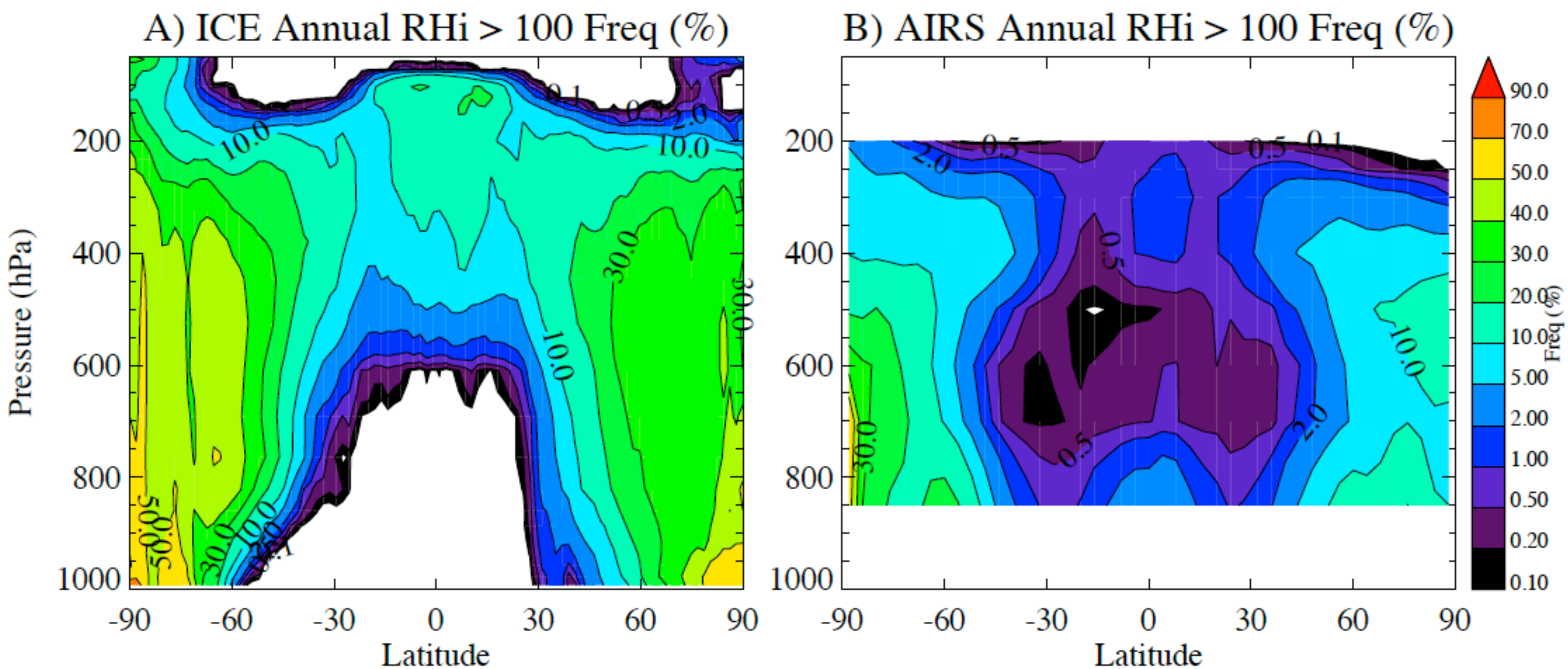


CAM5: Ice Supersaturation PDF



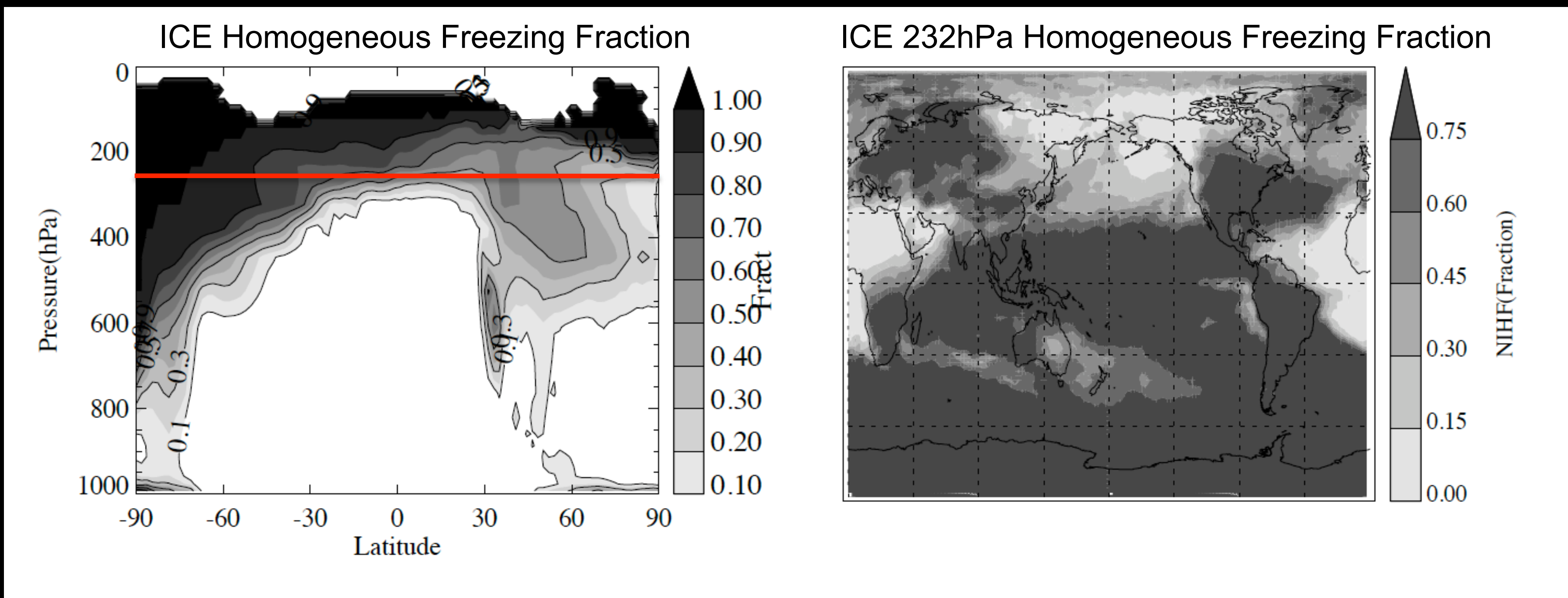
Gettelman et al 2006; Gettelman et al 2010

CAM5: Ice Supersaturation Frequency



CAM5: Homogenous Freezing

Homogeneous Freezing contribution to ice crystal number

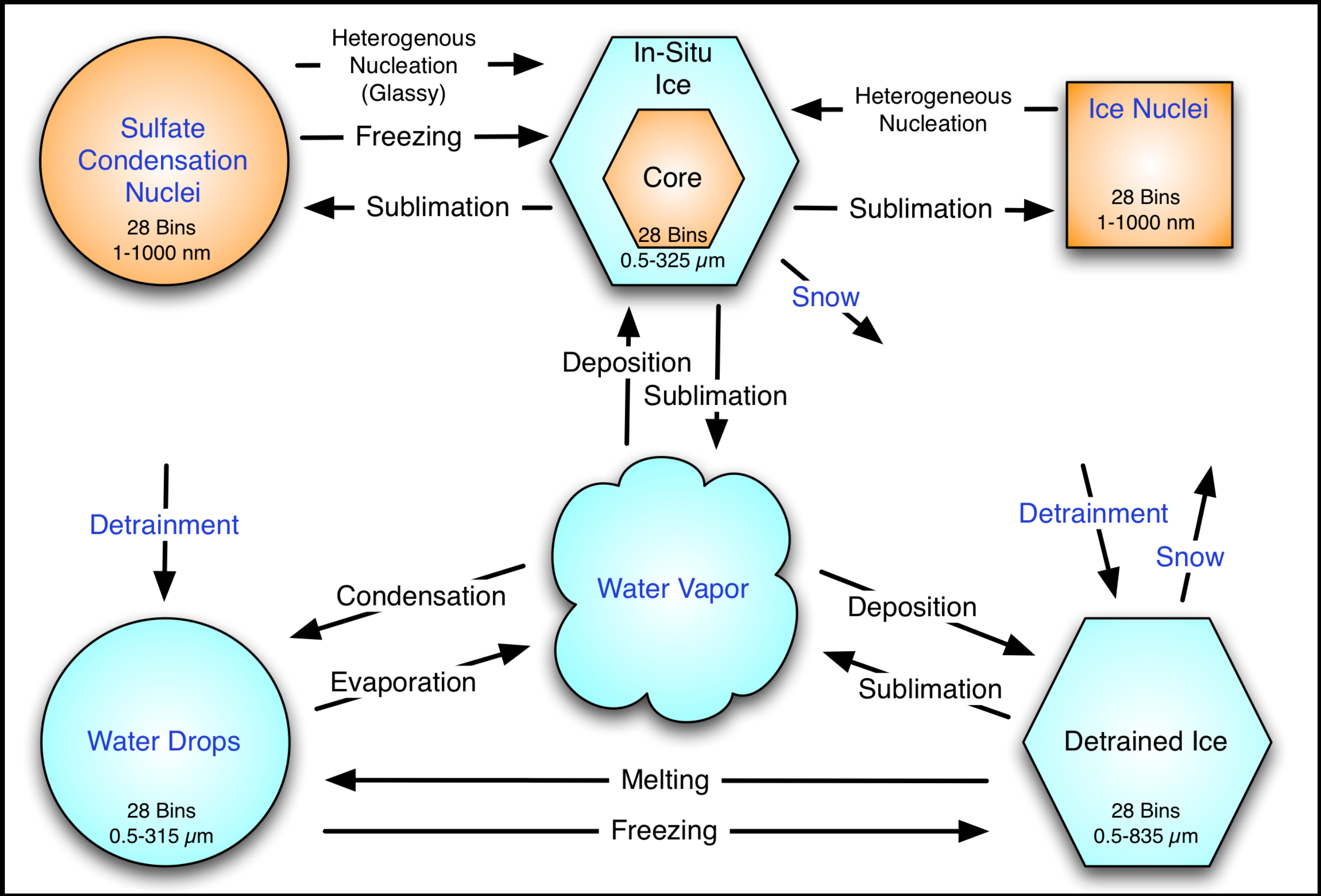


Gettelman et al 2010, in Press JGR

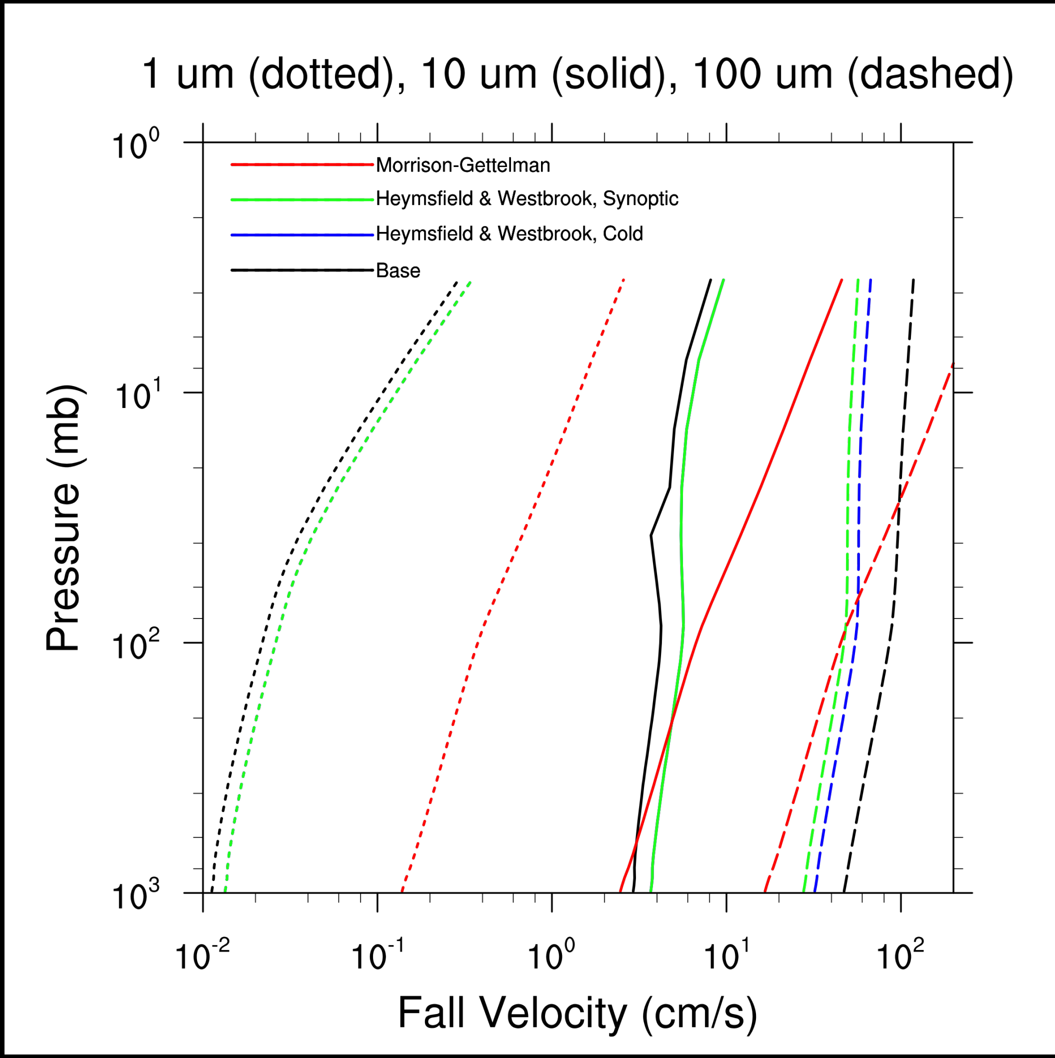
CAM/CARMA Microphysics

- Sectional Ice + Two Moment Liquid
  - Size resolved ice (CARMA, Toon et al. 1988, Jacobsen et al. 1994)
  - Separately track in situ and detrained ice
  - Improved sedimentation velocities
  - Increased vertical resolution (~300 m in the TTL)
- In Situ Ice
  - Hexagonal plates, AR=6 (Lawson et al. 2008), bulk ice density
  - Homogeneous freezing (Koop et al. 2000, Möhler et al. 2010?)
  - Heterogeneous nucleation of glassy aerosols (Murray et al. 2010)
  - Heterogeneous nucleation of dust and soot
- Detrained Ice
  - Spheres, variable density (Heymsfield & Schmitt, 2010)
  - Detrain as a size distribution (temperature dependent) (Heysmfield & Schmitt, 2010)
- Radiation
  - Both bulk (two moment) and size resolved treatments

CAM/CARMA Microphysics

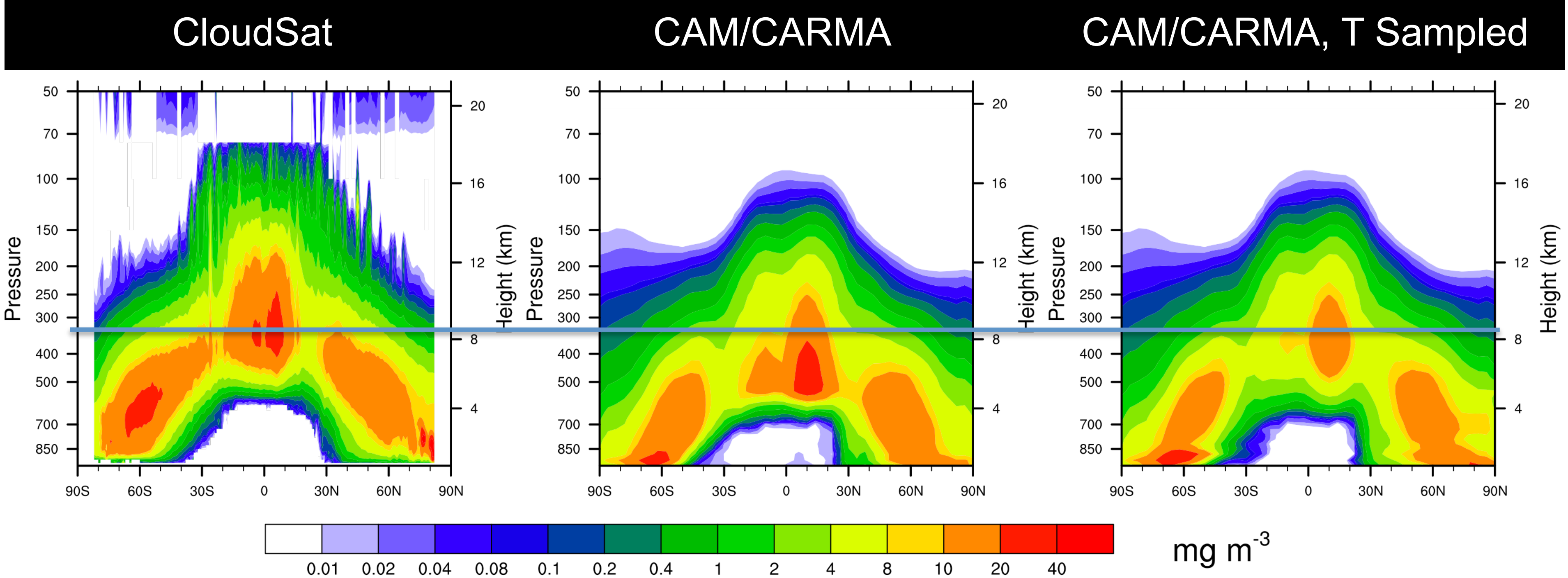


CAM/CARMA Fall Velocities for Detrained Ice

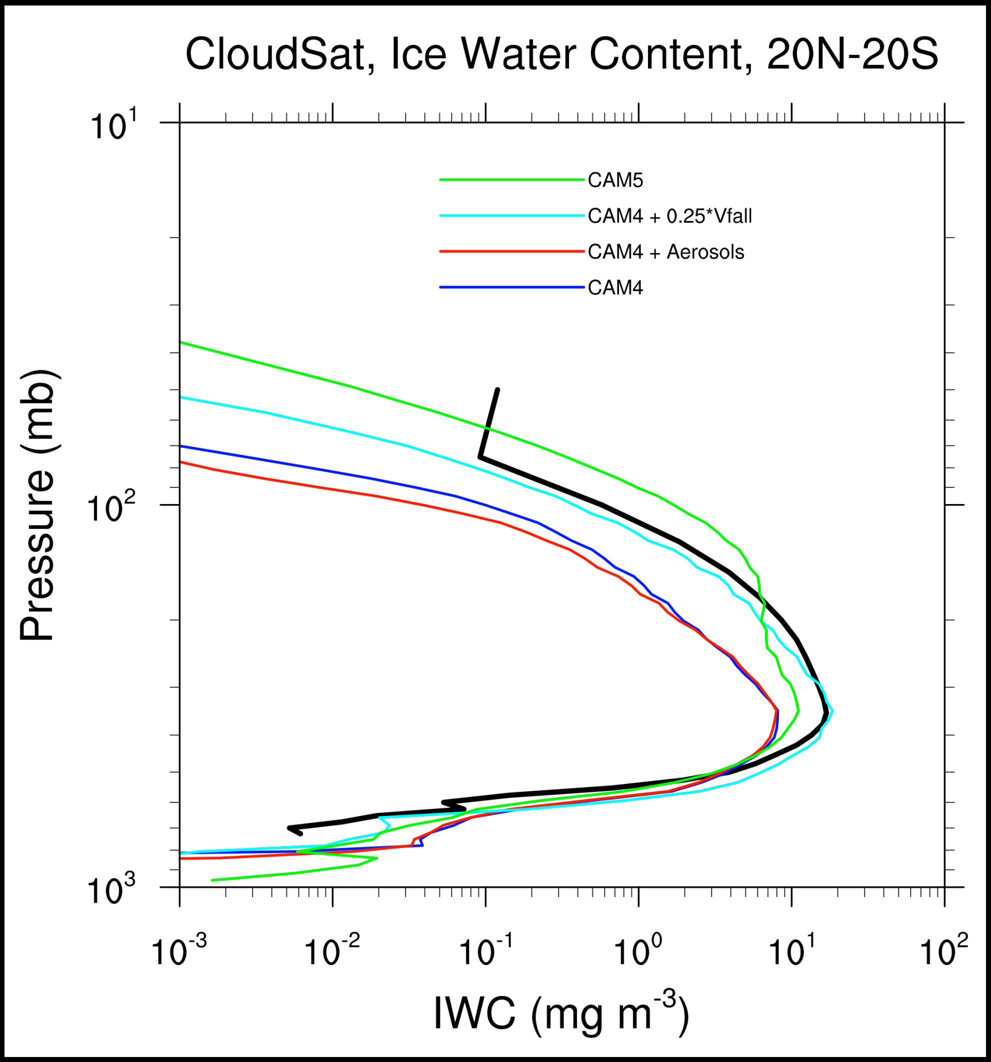


CAM/CARMA Microphysics

Ice Water Content



CAM/CARMA Tropical IWC
(T Sampled)



CAM in ATTREX: Science Goals

1. To improve our understanding of how deep convection, slow large-scale ascent, waves, and cloud macrophysics control the humidity and chemical composition of air entering the stratosphere.
   – Process studies
   – Evaluate and improve model parameterizations
   – New Parameterizations in CAM5 (UW shallow convection, MG & CARMA microphysics, macrophysics, modal aerosols, RRTMG radiation, …)
2. To improve global-model predictions of feedbacks associated with future changes in TTL cirrus, stratospheric humidity, and stratospheric ozone in a changing climate.
   – Climate change studies (IPCC Assessments)
   – Chemistry climate studies (IPCC and WMO Assessments)

ATTREX/GCM: Science Questions

- What are the formation processes, microphysical properties, and radiative properties of TTL cirrus clouds?
- What is the climate impact of TTL cirrus?
- How do TTL cirrus regulate the humidity of air entering the stratosphere?
  - ATTREX: T, H_2O, Clouds (ice properties, radiative fluxes, lidar), tracers, waves
  - Others: CloudSat & Calipso IWC, COSMIC T, MLS H_2O, …
  - Flights: In, above and below cloud; in situ & detrained cloud; longitudinal survey; seasonal survey

- What is the evolution of TTL Cirrus radiative and microphysical properties and their environment?
  - ATTREX: T, H_2O, Clouds (ice properties, radiative fluxes, lidar), tracers
  - Others: CloudSat & Calipso IWC, COSMIC T, MLS H_2O, …
  - Flights: Lagrangian Survey with data in, above and below cloud.

ATTREX/GCM Science, con't

- What processes control the tropical tropopause temperature and the humidity of air entering the stratosphere (including their seasonal cycles)?
  - ATTREX: T, H_2O, Clouds (ice properties, radiative fluxes, lidar), waves
  - Others: aerosols?, dynamical tracers? (O_3, CO_2, …)
  - Flights: longitudinal survey, seasonal survey, in-cloud sampling. Vertical structure (circles?), Coordination with radiosondes/balloons.

- What are the dominant pathways/processes for vertical transport from convective detrainment altitudes in the TTL up to the tropical tropopause in different seasons?
- What are the mechanisms for horizontal and meridional mixing of air between the tropics and sub-tropics subsequent to convective detrainment?
  - ATTREX: T, H_2O, other tracers (HCN, CO, O3, correlations), radiative fluxes
  - Others: ACE HDO, dynamical tracers? (O_3, CO_2, …)
  - Flights: Lagrangian sampling, vertical structure (dives through TTL). Meridional survey at convective outflow level and just above tropopause. Coordination with GV?

Summary

- CAM (GCM) now has:
  – Ice supersaturation and ice nucleation
  – Optional bin microphysical model for cirrus
- Goals:
  – Use process studies (ATTREX) to understand TTL processes & improve models
  – Use validated models to simulate future of climate & chemistry